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Tsirkin

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(54) **OFFLINE RADIX TREE COMPRESSION WITH KEY SEQUENCE SKIP**

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CPC ***G06F 17/30961*** (2013.01); ***G06F 17/30153*** (2013.01)

(58) **Field of Classification Search**
CPC G06F 17/30
USPC 707/600–899
See application file for complete search history.

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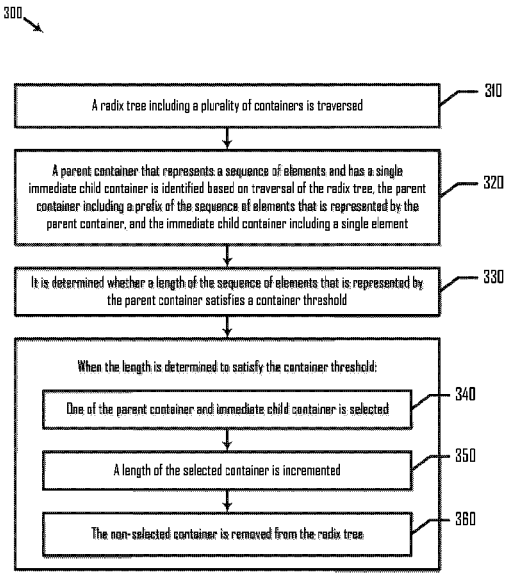
(74) *Attorney, Agent, or Firm* — Haynes and Boone, LLP

(57) **ABSTRACT**

Systems and methods are disclosed for compressing a radix tree. An example method of compressing a radix tree including a plurality of containers includes traversing a radix tree including a plurality of containers. The method also includes identifying, based on the traversing, a parent container that represents a sequence of elements and has a single immediate child container. The parent container includes a prefix of the sequence of elements that is represented by the parent container, and the immediate child container includes a single element. The method further includes determining whether a length of the sequence of elements that is represented by the parent container satisfies a container threshold. The method also includes when the length is determined to satisfy the container threshold, selecting one of the parent container and immediate child container, incrementing a length of the selected container, and removing the non-selected container from the radix tree.

20 Claims, 7 Drawing Sheets



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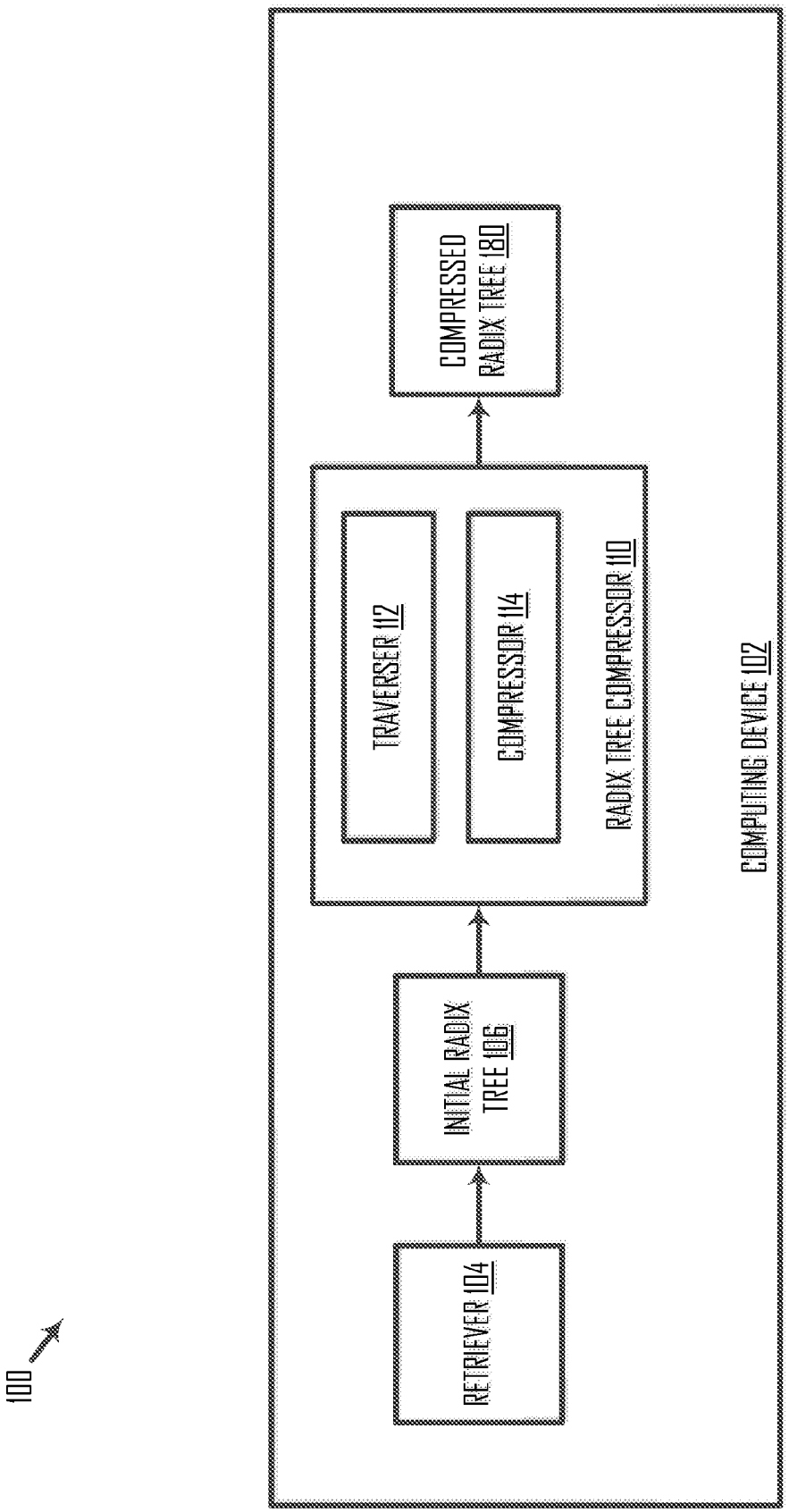
100
RETRIEVER 104
INITIAL RADIX TREE 106
RADIX TREE COMPRESSOR 110
TRAVERSER 112
COMPRESSOR 114
COMPRESSED RADIX TREE 180
COMPUTING DEVICE 102

FIG. 1

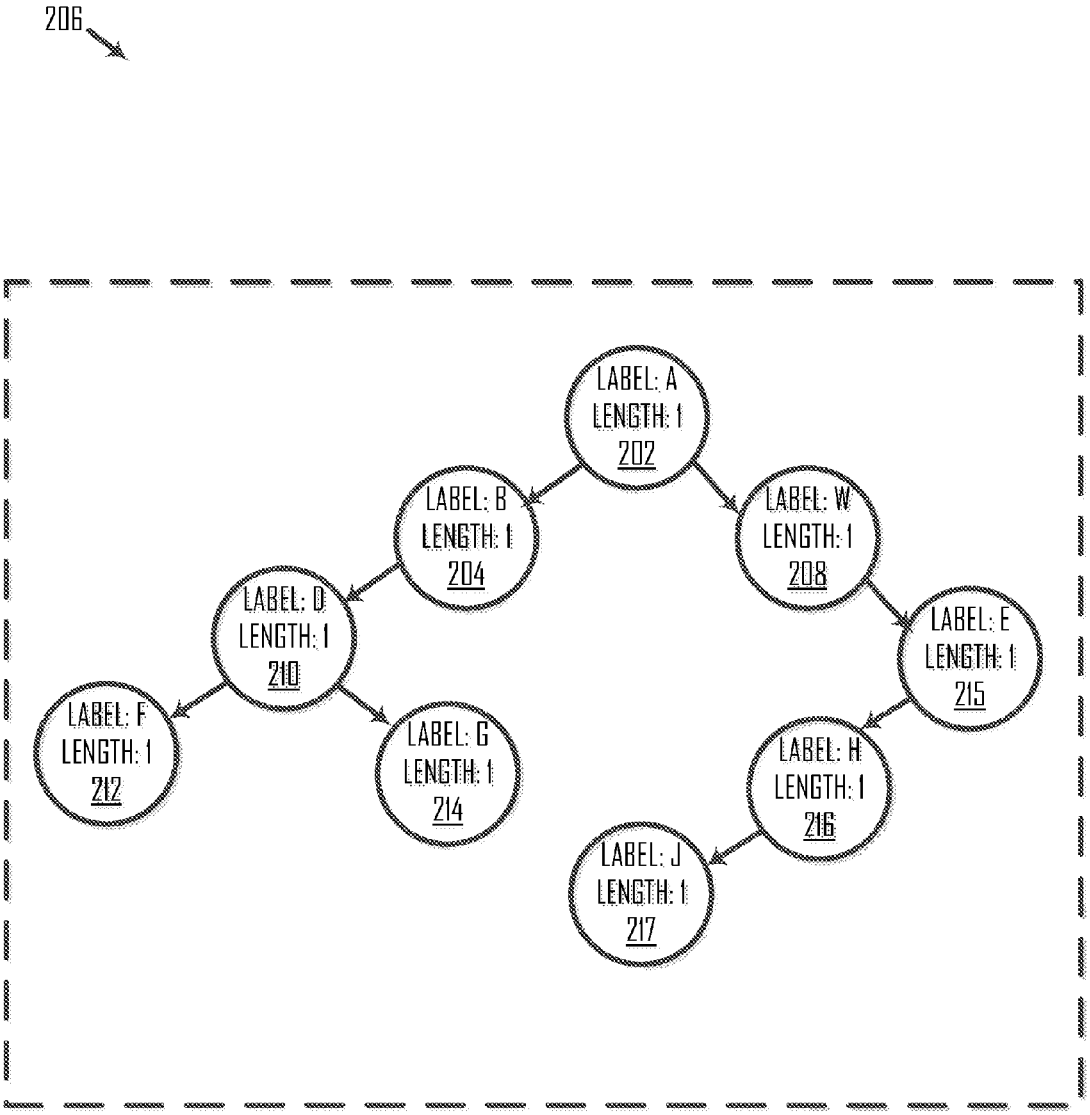
206
LABEL: A
LENGTH: 1
202
LABEL: B
LENGTH: 1
204
LABEL: W
LENGTH: 1
208
LABEL: D
LENGTH: 1
210
LABEL: E
LENGTH: 1
215
LABEL: F
LENGTH: 1
212
LABEL: G
LENGTH: 1
214
LABEL: H
LENGTH: 1
216
LABEL: J
LENGTH: 1
217

FIG. 2A

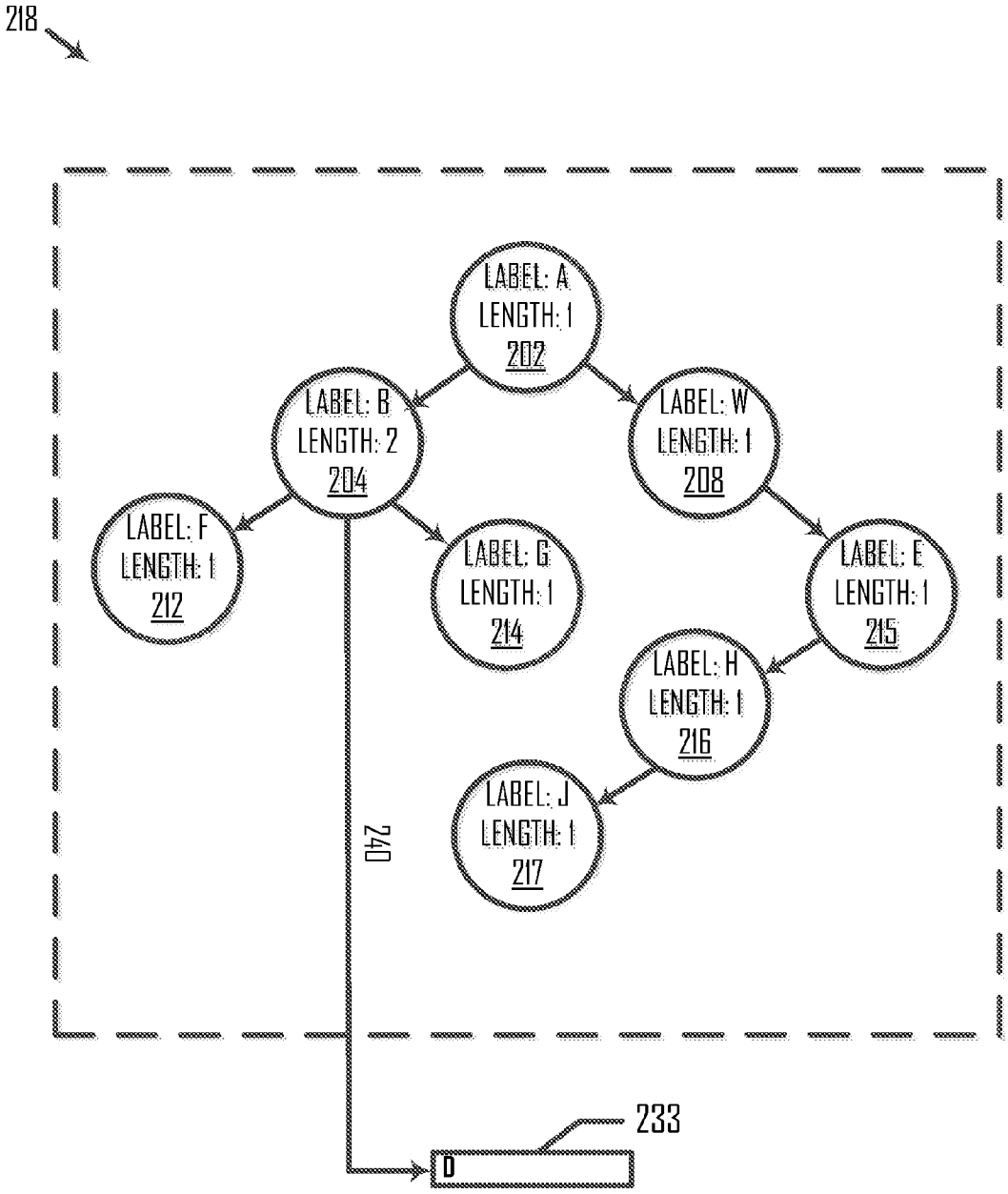
218
LABEL: A
LENGTH: 1
202
LABEL: B
LENGTH: 2
204
LABEL: W
LENGTH: 1
208
LABEL: F
LENGTH: 1
212
LABEL: G
LENGTH: 1
214
LABEL: E
LENGTH: 1
215
LABEL: H
LENGTH: 1
216
LABEL: J
LENGTH: 1
217
240
233
D

FIG. 2B

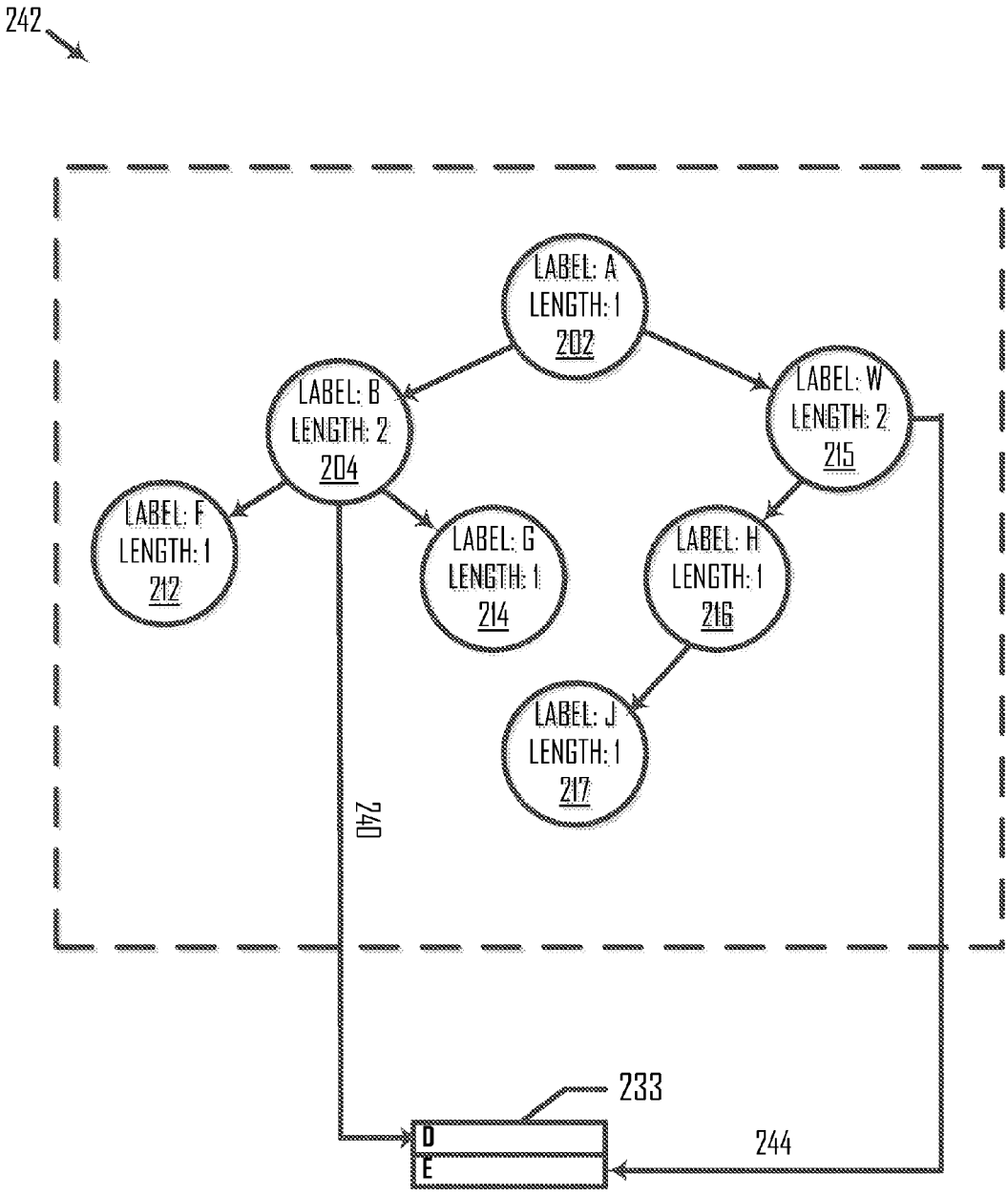
242
LABEL: A
LENGTH: 1
202
LABEL: B
LENGTH: 2
204
LABEL: W
LENGTH: 2
215
LABEL: F
LENGTH: 1
212
LABEL: G
LENGTH: 1
214
LABEL: H
LENGTH: 1
216
LABEL: J
LENGTH: 1
217
240
233
D
E
244

FIG. 2C

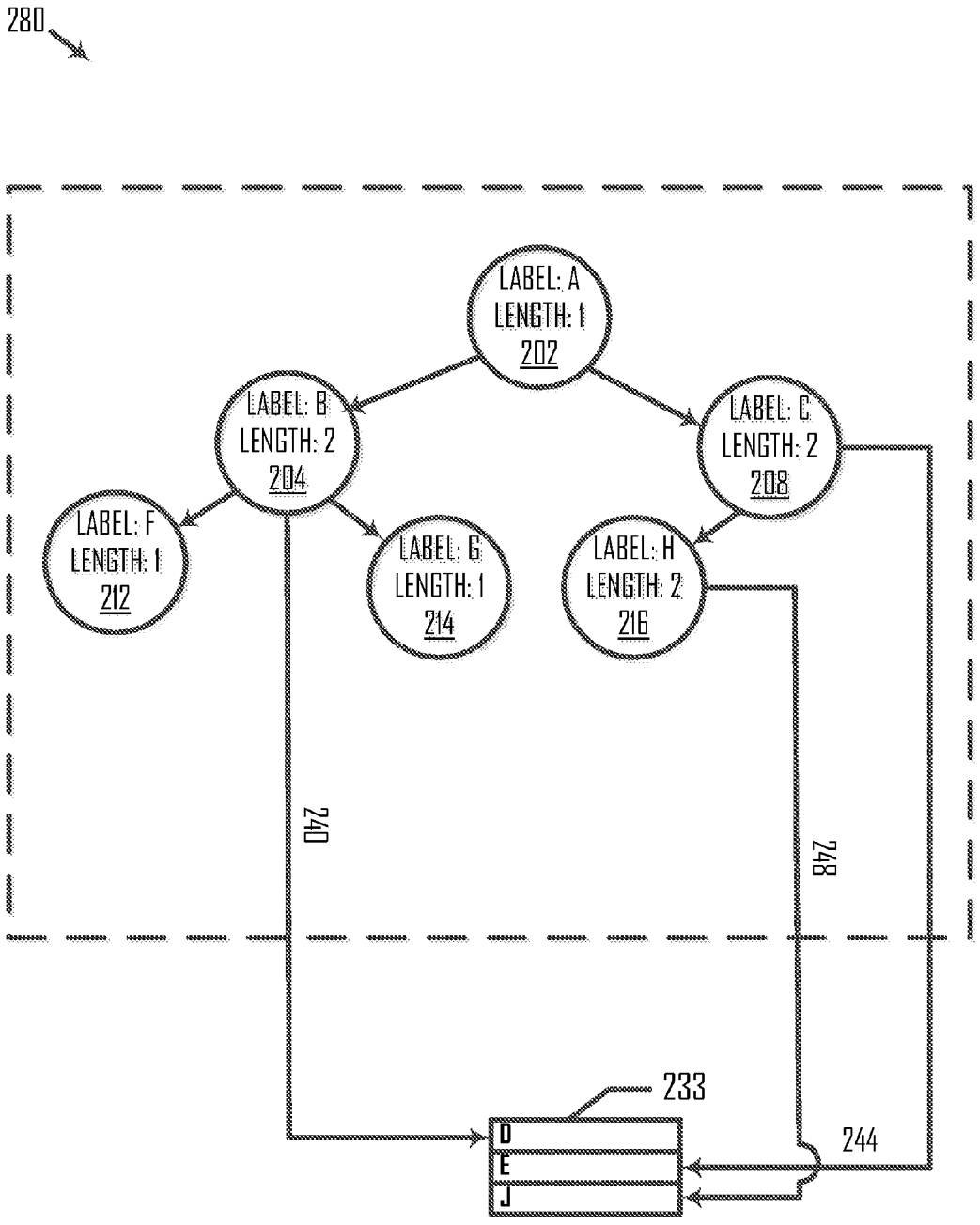
280
LABEL: A
LENGTH: 1
202
LABEL: B
LENGTH: 2
204
LABEL: C
LENGTH: 2
208
LABEL: F
LENGTH: 1
212
LABEL: G
LENGTH: 1
214
LABEL: H
LENGTH: 2
216
240
248
233
D
E
J
244

FIG. 2D

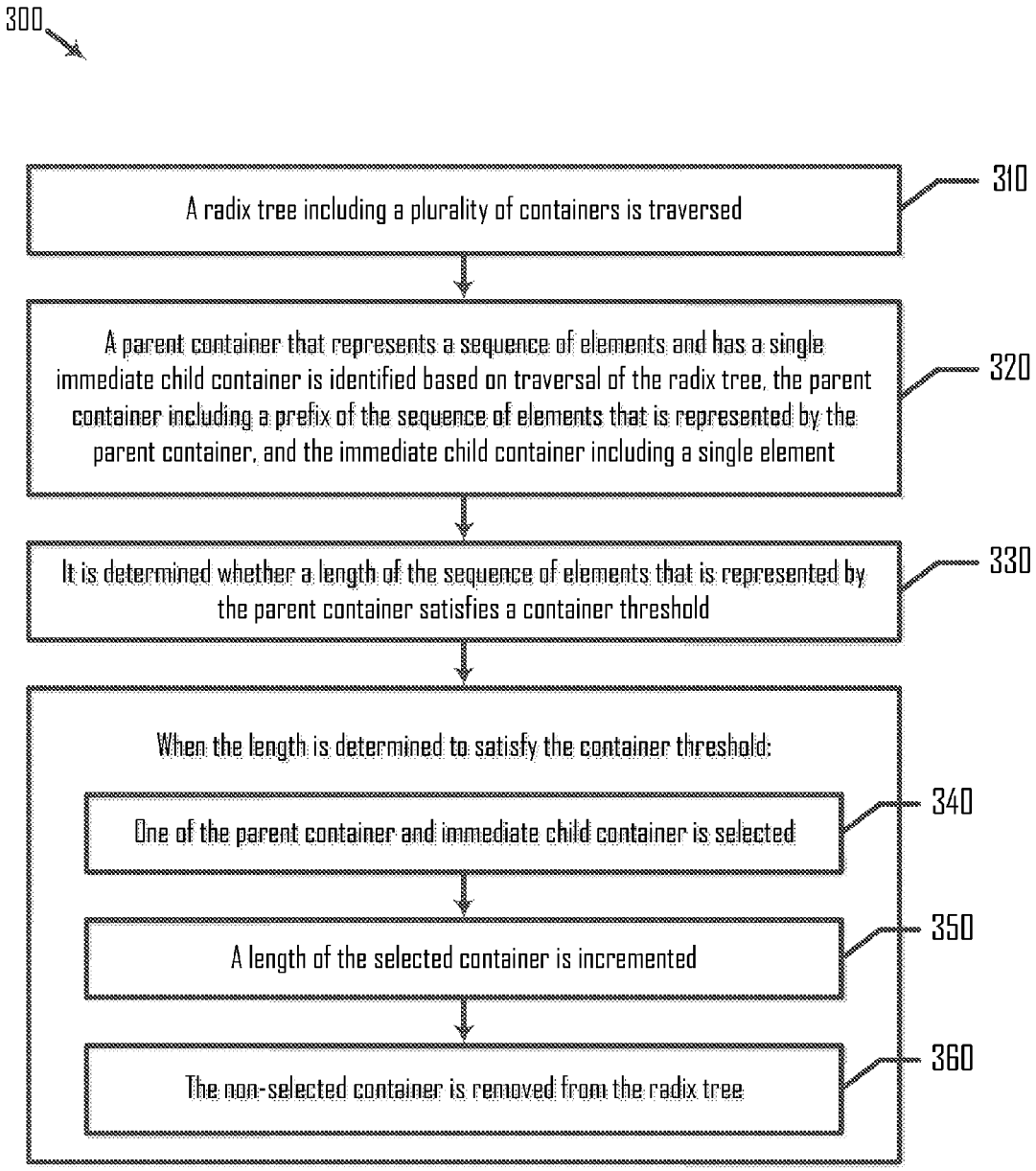
300
A radix tree including a plurality of containers is traversed
310
A parent container that represents a sequence of elements and has a single immediate child container is identified based on traversal of the radix tree, the parent container including a prefix of the sequence of elements that is represented by the parent container, and the immediate child container including a single element
320
It is determined whether a length of the sequence of elements that is represented by the parent container satisfies a container threshold
330
When the length is determined to satisfy the container threshold:
One of the parent container and immediate child container is selected
340
A length of the selected container is incremented
350
The non-selected container is removed from the radix tree
360

FIG. 3

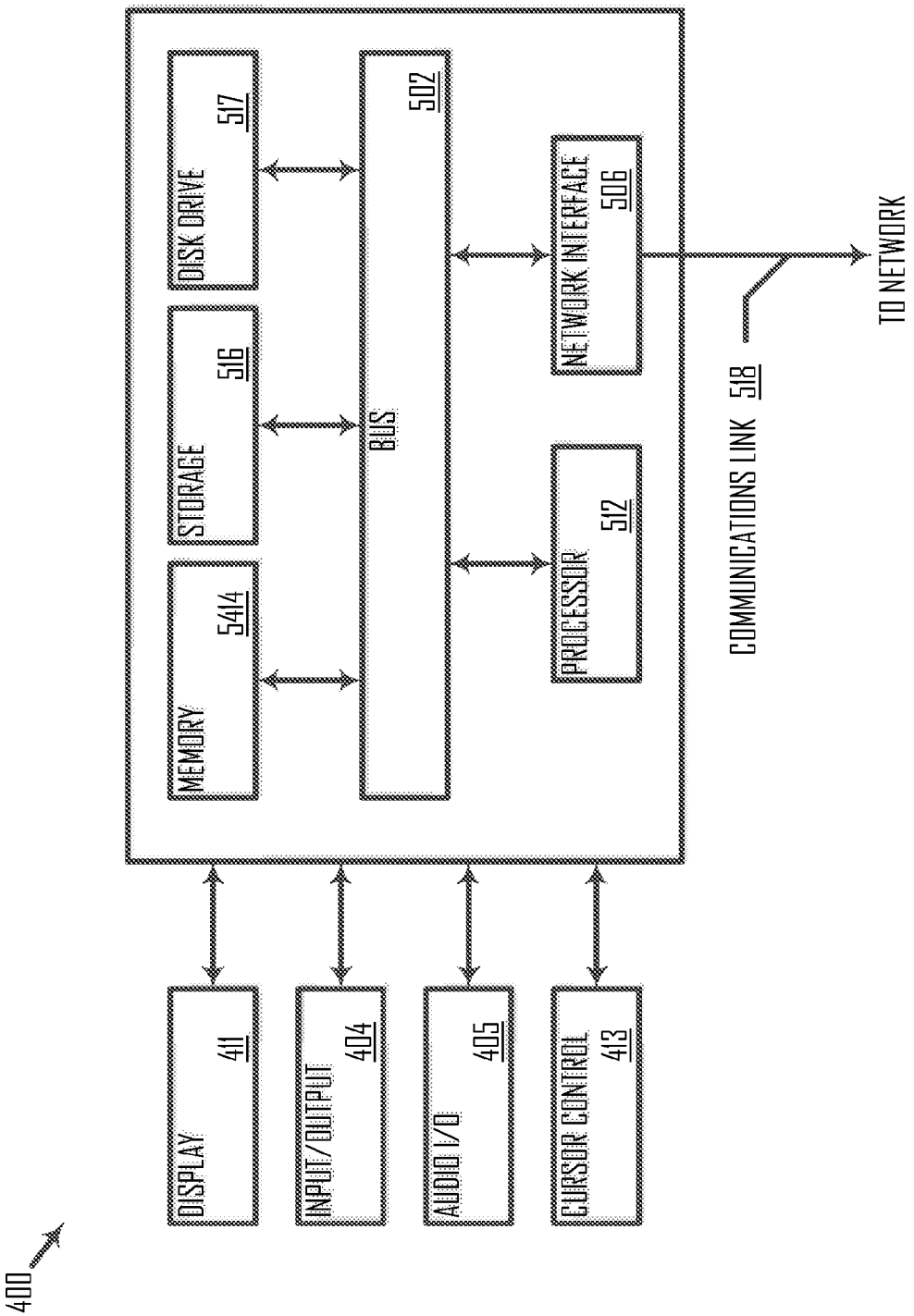
400
DISPLAY 411
INPUT/OUTPUT 404
AUDIO I/O 405
CURSOR CONTROL 413
MEMORY 5414
STORAGE 516
DISK DRIVE 517
BUS 502
PROCESSOR 512
NETWORK INTERFACE 506
COMMUNICATIONS LINK 518
TO NETWORK

FIG. 4

OFFLINE RADIX TREE COMPRESSION WITH KEY SEQUENCE SKIP

BACKGROUND

The present disclosure generally relates to a radix tree, and more particularly to compressing a radix tree.

A radix tree is a data structure that is used to store data. A radix tree may be useful for constructing associative arrays with keys that can be expressed as strings and typically supports insertion, deletion, and search operations. The insertion operation adds a new string to the radix tree while trying to minimize the amount of data stored. The deletion operation removes a string from the radix tree. A search operation may include an exact lookup of a string, a lookup of a predecessor or successor of the string, or a lookup of all strings with a particular prefix.

BRIEF SUMMARY

This disclosure relates to compressing a radix tree. Methods, systems, and techniques for compressing a radix tree are provided.

According to an embodiment, a method of compressing a radix tree including a plurality of containers includes traversing a radix tree including a plurality of containers. The method also includes identifying, based on the traversing, a parent container that represents a sequence of elements and has a single immediate child container. The parent container includes a prefix of the sequence of elements that is represented by the parent container. The immediate child container includes a single element. The method further includes determining whether a length of the sequence of elements that is represented by the parent container satisfies a container threshold. The method also includes when the length is determined to satisfy the container threshold, selecting one of the parent container and immediate child container, incrementing a length of the selected container, and removing the non-selected container from the radix tree.

According to another embodiment, a system for compressing a radix tree including a plurality of containers includes a traverser that traverses a radix tree including a plurality of containers and identifies, based on the traversal of the radix tree, a parent container that represents a sequence of elements and has a single immediate child container. The parent container includes a prefix of the sequence of elements that is represented by the parent container, and the immediate child container includes a single element. The system also includes a compressor that determines whether a length of the sequence of elements that is represented by the parent container satisfies a container threshold. When the length is determined to satisfy the container threshold, the compressor selects one of the parent container and immediate child container, increments a length of the selected container, and removes the non-selected container from the radix tree.

According to another embodiment, a non-transitory machine-readable medium includes a plurality of machine-readable instructions that when executed by one or more processors are adapted to cause the one or more processors to perform a method including: traversing a radix tree including a plurality of containers; identifying, based on the traversing, a parent container that represents a sequence of elements and has a single immediate child container, the parent container including a prefix of the sequence of elements that is represented by the parent container, and the immediate child container including a single element; determining whether a length of the sequence of elements that is represented by the parent container satisfies a container threshold; and when the length is determined to satisfy the container threshold: selecting one of the parent container and immediate child container; incrementing a length of the selected container; and removing the non-selected container from the radix tree.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which form a part of the specification, illustrate embodiments of the invention and together with the description, further serve to explain the principles of the embodiments. Embodiments of the present disclosure and their advantages are best understood by referring to the detailed description that follows. In the drawings, like reference numbers may indicate identical or functionally similar elements. The drawing in which an element first appears is generally indicated by the left-most digit in the corresponding reference number.

FIG. **1** is a block diagram illustrating a system for compressing a radix tree including a plurality of containers, according to an embodiment.

FIG. **2**A is a block diagram illustrating an initial radix tree including a plurality of containers, according to an embodiment.

FIG. **2**B is a block diagram illustrating a first intermediate radix tree resulting from the compression of the initial radix tree in FIG. **2**A, according to an embodiment.

FIG. **2**C is a block diagram illustrating a second intermediate radix tree resulting from the compression of the first intermediate radix tree in FIG. **2**B, according to an embodiment.

FIG. **2**D is a block diagram illustrating a compressed radix tree resulting from the compression of the intermediate radix tree in FIG. **2**C, according to an embodiment.

FIG. **3** is a flowchart illustrating a method of compressing a radix tree including a plurality of containers, according to an embodiment.

FIG. **4** is a block diagram of an electronic system suitable for implementing one or more embodiments of the present disclosure.

DETAILED DESCRIPTION

I. Overview
II. Example System Architecture
A. Example Radix Tree
B. Traverse the Radix Tree
C. Compress the Radix Tree
1. Identify Containers to Combine
2. The Parent Container is Selected
3. Continue the Traversal of the Radix Tree
4. The Immediate Child Container is Selected
5. Continue the Traversal of the Radix Tree
III. Example Method
IV. Example Computing System

I. Overview

It is to be understood that the following disclosure provides many different embodiments, or examples, for implementing different features of the present disclosure. Some embodiments may be practiced without some or all of these specific details. Specific examples of components, modules, and arrangements are described below to simplify the present disclosure. These are, of course, merely examples and are not intended to be limiting.

A radix tree may store one or more keys. If the radix tree stores a key that starts with 100 "0"s, the radix tree may have a depth of 100, stretching down to 100 levels. After the first 100 levels, the path may branch out. It may be time consuming to traverse the radix tree following a single path for 100 levels. It may be desirable to compress the radix tree.

Further, keys stored in the radix tree may have different lengths. To implement such a radix tree, memory to store the radix tree may be dynamically allocated or may be pre-allocated to ensure that sufficient memory is available to store the longest possible key for each node in the radix tree. Dynamically allocating memory and pre-allocating memory for a radix tree may have performance issues.

Unless specifically stated otherwise, as apparent from the following discussion, it is appreciated that throughout the description, discussions utilizing terms such as "receiving", "identifying", "traversing", "determining", "selecting", "incrementing", and "removing" or the like, refer to the action and processes of a computer system, or similar electronic computing device, that manipulates and transforms data represented as physical (electronic) quantities within the computer system's registers and memories into other data similarly represented as physical quantities within the computer system memories or registers or other such information storage, transmission or display devices.

II. Example System Architecture

FIG. **1** is a block diagram **100** illustrating a system for compressing a radix tree including a plurality of containers, according to an embodiment. Diagram **100** includes a computing device **102**. Computing device **102** may be a workstation, computer, server, game console, set-top box, kiosk, embedded system, mobile device (e.g., a mobile phone, personal digital assistant, tablet, and laptop), or other device having at least one processor and memory.

FIG. **1** also includes a retriever **104** and a radix tree compressor **110**. Each of retriever **104** and radix tree compressor **110** is executable on computing device **102**. Retriever **104** or radix tree compressor **110** may receive an instruction to compress an initial radix tree **106**. Retriever **104** retrieves initial radix tree **106** stored in memory. A radix tree includes one or more containers and stores one or more keys. Initial radix tree **106** may include containers that have zero or more children. A node has a one-to-one relationship with an incoming edge, and the container may be a node or an edge of the radix tree. A key includes a sequence of elements. An element may be, for example, a symbol, character, letter, number, or bit. Other elements are within the scope of the disclosure.

The key may map to a value that is referenced by a leaf container in the radix tree. In an example, a key is a sequence of bits that represents an address in memory. In such an example, the key may represent an address supplied in an instruction (e.g., input/output (I/O) address for a port I/O or a physical memory address for memory I/O) that maps to a "target" that indicates the instruction type. In another example, a key is a word including a sequence of letters. In such an example, the radix tree may be used to index words in a text document.

Radix tree compressor **110** traverses initial radix tree **106** and compresses it, thereby creating a compressed radix tree **180**. In an example, radix tree compressor **110** compresses initial radix tree **106** offline. In an example, after the initial radix tree stores the keys and is complete, radix tree compressor **110** traverses and compresses the initial radix tree.

A. Example Radix Tree

FIG. **2**A is a block diagram illustrating an initial radix tree **206** including a plurality of containers, according to an embodiment. FIG. **2**B is a block diagram illustrating an intermediate radix tree **218** resulting from the compression of initial radix tree **206** in FIG. **2**A, according to an embodiment. FIG. **2**C is a block diagram illustrating an intermediate radix tree **242** resulting from the compression of intermediate radix tree **218** in FIG. **2**B, according to an embodiment. FIG. **2**D is a block diagram illustrating a compressed radix tree **280** resulting from the compression of intermediate radix tree **242** in FIG. **2**C, according to an embodiment. The description below will refer to FIGS. **2**A-**2**D together to explain in further detail how radix tree compressor **110** compresses initial radix tree **206** to thereby create compressed radix tree **280**.

In FIG. **2**A, initial radix tree **206** includes one or more containers and stores one or more keys. Each container in initial radix tree **206** has zero or more children and may represent a sequence of elements. Additionally, each container may include one or more fields. In an example, a container includes a label field and a length field. A container's label field may have as its value a prefix of a sequence of elements that is represented by the container. The length of the prefix may be up to a prefix threshold. The prefix threshold enables the number of elements included in a container to be limited. The smaller the prefix threshold is the fewer elements that can be stored in a container. In contrast, the larger the prefix threshold is the more elements that can be stored in the container. It may be desirable to limit the number of elements that can be stored in a container to limit the size of the container. The value of a container's label field may be the container's prefix.

A container's length field may have as its value the length of the sequence of elements that is represented by the container. The value of a container's length field may be referred to as the container's length and may identify the number of elements that the container represents. A container may represent one or more elements. One or more elements represented by a container may be "skipped" or removed and represented in the container's length, as will be discussed further below.

Initial radix tree **206** includes a root container **202**. Root container **202** is located at a depth of zero in initial radix tree **206** and includes a single element "A", which is container **202**'s label field value and is a prefix of a sequence of elements "A" that is represented by container **202**. Root container **202**'s length field value is one, which is the length of the sequence of elements that is represented by container **202**. The length of the prefix may be up to a prefix threshold. The prefix threshold may be any whole number greater than zero.

Root container **202** has two immediate children, containers **204** and **208**, which are located at a depth of one in initial radix tree **206**. An immediate child container of a parent container refers to a direct edge relationship between two containers. The immediate child may be located one depth level below the parent container. In an example, containers **204** and **208** are immediate children of root container **202**. A single edge connects root container **202** to container **204**, which is one depth level below root container **202**. In contrast, although container **210** is a descendant of root node **202**, container **210** is not an immediate child container of root node **202**. A single edge does not connect root container **202** to container **210**, which is more than one depth level below root container **202**.

Container **204** includes a single element "B", which is container **204**'s label field value and is a prefix of a sequence of elements "B" that is represented by container **204**. Con-

tainer **204**'s length field value is one, which is the length of the sequence of elements "B" that is represented by container **204**. Container **208** includes a single element "W", which is container **208**'s label field value and is a prefix of a sequence of elements "W" that is represented by container **208**. Container **208**'s length field value is one, which is the length of the sequence of elements "W" that is represented by container **208**.

Container **204** has a single immediate child, container **210**, which is located at a depth of two in initial radix tree **206**. Container **210** includes a single element "D", which is container **210**'s label field value and is a prefix of a sequence of elements "D" that is represented by container **210**. Container **210**'s length field value is one, which is the length of the sequence of elements "D" that is represented by container **210**. Container **210** has two immediate children, containers **212** and **214**, which are located at a depth of three in initial radix tree **206**. Container **212** includes a single element "F", which is container **212**'s label field value and is a prefix of a sequence of elements "F" that is represented by container **212**. Container **212**'s length field value is one, which is the length of the sequence of elements "F" that is represented by container **212**. Container **214** includes a single element "G", which is container **214**'s label field value and is a prefix of a sequence of elements "G" that is represented by container **214**. Container **214**'s length field value is one, which is the length of the sequence of elements "G" that is represented by container **214**.

Container **208** has a single immediate child, container **215**, which is located at a depth of two in initial radix tree **206**. Container **215** includes a single element "E", which is container **215**'s label field value and is a prefix of a sequence of elements "E" that is represented by container **215**. Container **215**'s length field value is one, which is the length of the sequence of elements "E" that is represented by container **215**. Container **215** has a single immediate child, container **216**, which is located at a depth of three in initial radix tree **206**. Container **216** includes a single element "H", which is container **216**'s label field value and is a prefix of a sequence of elements "H" that is represented by container **216**. Container **216**'s length field value is one, which is the length of the sequence of elements "H" that is represented by container **216**. Container **216** has a single immediate child, container **217**, which is located at a depth of four in initial radix tree **206**. Container **217** includes a single element "J", which is container **217**'s label field value and is a prefix of a sequence of elements "J" that is represented by container **217**. Container **217**'s length field value is one, which is the length of the sequence of elements "J" that is represented by container **217**. Containers **212**, **214**, and **217** are leaf containers because they have no children.

Initial radix tree **206** may store three keys. In an example, a first key "ABDF" is stored in containers **202**, **204**, **210**, and **212**. Container **212** may map to a value that is associated with the first key (not shown). A second key "ABDG" is stored in containers **202**, **204**, **210**, and **214**. Container **214** maps to a value that is associated with the second key (not shown). A third key "AWEHJ" is stored in containers **202**, **208**, **215**, **216**, and **217**. Container **217** maps to a value that is associated with the third key (not shown). In another example, initial radix tree **206** stores the prefix of one or more keys and stores more elements than that shown in FIG. **2**A. For example, initial radix tree **206** stores a key "ABDFR" and only the first four elements of the key are shown in FIG. **2**A (e.g., in containers **202**, **204**, **210**, and **212**).

B. Traverse the Radix Tree

Radix tree compressor includes a traverser **112** and a compressor **114**. When a lookup for a key in a radix tree occurs, traverser **112** may traverse the radix tree to search for the key. Traverser **112** may traverse initial radix tree **206** container by container and identify the element included in one or more traversed containers. Traverser **112** may traverse initial radix tree **206** from root container **202** towards a leaf container of the radix tree. A traversal of a compressed radix tree is described in U.S. patent application Ser. No. 14/272,445 to Tsirkin et al., filed May 7, 2014, entitled "Lookup with Key Sequence Skip for Radix Tree," which is incorporated herein by reference in its entirely.

In an example, traverser **112** starts from the root container, which may store a first set of elements of the key that is being searched for. Traverser **112** then looks at the root container's children to search for the next sequence of one or more elements in the searched-for key after the first set of elements included in the root container. A leaf container may be associated with a value to which the key is mapped. In an embodiment, a leaf container of a key identifies a value to which the key maps, and the value is associated with the key. Traverser **112** may look in the leaf container to identify the value to which the key maps. In an example, the value may be inserted in the leaf container. In another example, the leaf container references or points to the value.

Traverser **112** may traverse the containers in initial radix tree **206** such that a parent of a given container is traversed before the given container is traversed. In an example, traverser **112** traverses initial radix tree **206** from top (e.g., root container **202**) down to a child container of the root container and continues to traverse the descendants of that child container until a leaf container is traversed. In such an example, traverser **112** may traverse root container **202**, container **204** (a child of root container **202**), container **210**, and leaf container **212** (a descendant and child of container **204**). If a container has more than one child, traverser **112** may traverse the container's other children. For example, after traversing container **204**, traverser **112** may traverse container **208** (the other child of root container **202**) and any children that container **208** may have. For example, after traversing container **208**, traverser **112** may traverse containers **215**, **216**, and **217**, which are descendants of container **202**.

In another example, traverser **112** starts at root container **202** at depth zero, goes down the next depth level and traverses each container at that depth level, and continues to go down one depth level at a time and traverse each container at that particular depth level before moving on to the next depth level. In such an example, traverser **112** may start at root container **202** at depth zero, traverse down to each of the containers at depth one (e.g., containers **204** and **208**), then traverse down to each of the containers at depth two (e.g., containers **210** and **215**), then traverse down to each of the containers at depth three (e.g., containers **212**, **216**, and **216**), and then traverse down to each of the containers at depth four (e.g., container **217**). Accordingly, containers having a smaller depth are traversed before containers having a larger depth in initial radix tree **206**. In other words, containers that are located closer to the root container are traversed before containers that are located farther from the root container. In such a traversal, the containers closer to the root node may store more elements than the containers farther from the root node. This, however, depends on how many children the containers have, as will be explained in further detail in the disclosure.

C. Compress the Radix Tree

I. Identify Containers to Combine

Radix tree compressor **110** may receive an instruction to compress initial radix tree **206**. When the instruction to compress initial radix tree **206** is received, traverser **112** may traverse the radix tree to identify containers in the radix tree to combine and/or remove. Traverser **112** may traverse initial radix tree **206** from root node **202** toward a leaf node of initial radix tree **206**.

In the example illustrated in FIG. **2**A, each container in initial radix tree **206** includes a single element, and the length of each set of elements included in a container is one. Accordingly, the amount of memory that each container takes up is small and limited. Further, initial radix tree **206** has a depth of four. It may be desirable to compress initial radix tree **206** such that its depth is reduced. By reducing initial radix tree **206**'s depth, it may take fewer steps to determine whether a key or a key's prefix is stored in initial radix tree **206**. Accordingly, searching of the compressed radix tree may be improved and the search time reduced, thus improving performance. For example, lookup time may be minimized and the number of memory accesses required during lookup reduced. Additionally, the size of initial radix tree **206** may be reduced such that it contains fewer containers.

In an embodiment, traverser **112** identifies, based on the traversal of initial radix tree **206**, a parent container that represents a sequence of elements and has a single immediate child container, where the parent container includes a prefix of the sequence of elements and the immediate child container includes a single element. Traverser **112** may traverse initial radix tree **206** until all of the containers are traversed, until most containers are traversed, until a particular number of containers are traversed, and/or until containers at a particular depth have been traversed.

When traverser **112** traverses root container **202**, traverser **112** may determine how many children root container **202** has. As illustrated in the example in FIG. **2**A, root container **202** has two immediate children. Because root container **202** does not have a single immediate child container (rather, root container **202** has two immediate child containers), root container **202** will not be combined with another container. Traverser **112** may continue down initial radix tree **206** and identify one or more of container **202**'s child containers. In particular, traverser **112** may go on to traverse container **204** and its children, and go on to traverse container **208** and its children. Although traverser **112** may be described as traversing container **204** and its descendants down to leaf containers **212** and **214** before traversing containers **208** and its children, this is not intended to be limiting and traverser **112** may traverse the containers in any order. For example, in another embodiment, traverser **112** traverses all of the containers at a particular depth level before traversing the containers located at a level below the particular depth level.

In an embodiment, compressor **114** determines whether a length of the sequence of elements that is represented by the parent container satisfies a container threshold. The container threshold may refer to the maximum number of elements that a container may represent. For example, if a container's container threshold is two, then the container may represent at most two elements. In an example, each container in initial radix tree **206** has the same container threshold. In another example, two containers in initial radix tree **206** have different container thresholds. In such an example, the container threshold of a container may depend on, for example, the depth level of the container.

The length of the sequence of elements that is represented by the parent container may satisfy the container threshold based on different conditions. In an example, when the length of the sequence of elements that is represented by the parent container does not exceed the container threshold, the length of the sequence of elements satisfies the container threshold. In another example, when the length of the sequence of elements that is represented by the parent container is less than the container threshold, the length of the sequence of elements satisfies the container threshold. In another example, when a sum of the length of the sequence of elements that is represented by the parent container and the length of the child container does not exceed the container threshold, the length of the sequence of elements satisfies the threshold. Other ways in which to compare the length of the sequence of elements that is represented by the parent container to the container threshold are within the scope of the disclosure. The container threshold may be set in accordance with the particular embodiment and how the length of the sequence of elements is compared to the container threshold.

When the length of the sequence of elements that is represented by the parent container is determined to satisfy the container threshold, compressor **114** selects one of the parent container and child container, increments a length of the selected container, and removes the non-selected container from the radix tree. In the example illustrated in FIG. **2**A, traverser **112** may traverse container **204**, and identify container **204** as being a parent container that represents a sequence of elements (e.g., sequence of elements "B") and also as having a single immediate child container (e.g., container **210**). Container **204** includes a prefix of the sequence of elements "B" that is represented by container **204**, and container **210** includes a single element "D".

In an example, the container threshold is two, and when the length of the sequence of elements that is represented by a parent container is less than the container threshold, the length of the sequence of elements that is represented by the parent container satisfies the container threshold. The length of the sequence of elements that is represented by parent container **204** is one, the value of container **204**'s length field. In such an example, compressor **114** determines whether the length of the sequence of elements that is represented by parent container **204** (e.g., one) is less than two, the container threshold. The length of the sequence of elements that is represented by parent container **204** is less than two. Accordingly, the length of the sequence of elements that is represented by container **204** satisfies the container threshold.

When compressor **114** determines that the length of the sequence of elements that is represented by container **204** does not satisfy the container threshold, traverser **112** may traverse another container. When compressor **114** determines that the length of the sequence of elements that is represented by container **204** satisfies the container threshold, compressor **114** selects one of container **204** and container **210**, increments a length of the selected container, and removes the non-selected container from initial radix tree **206**. In an embodiment, compressor **114** inserts the single element included in the immediate child container into an auxiliary data structure and stores a reference from the selected container to the auxiliary data structure. In an example, compressor **114** stores the single element in an entry in auxiliary data structure **233** and stores a reference from the selected container to the entry in the auxiliary data structure.

It is advantageous for compressor **114** to know that the traversed containers in initial radix tree **206** include only a single element. Accordingly, once compressor **114** determines that the length of the sequence of elements that is represented by the parent container satisfies the container threshold, compressor **114** may automatically select one of

the parent container and child container, increment a length of the selected container, and remove the non-selected container from the radix tree. It may be unnecessary for compressor **114** to determine a sum of the parent container's length and the immediate child container's length because the parent container's length will be extended by only a single element. This may save time and processing power.

2. The Parent Container is Selected

In an example, compressor **114** selects the parent container, which makes the immediate child container of the parent container the non-selected container. In such an example, compressor **114** selects container **204** and increments a length of container **204** by incrementing the length of the sequence of elements that is represented by container **204** by one. For example, compressor **114** may increment a length of container **204** by incrementing container **204**'s length by one. As illustrated in FIG. **2**B, container **204**'s length is incremented by one to incorporate container **210**'s length of one. Accordingly, in FIG. **2**B, the length of the sequence of elements that is represented by parent container **204** is two, the value of container **204**'s length field.

Additionally, compressor **114** removes container **210**, the non-selected container, from initial radix tree **206**. As illustrated in FIG. **2**B, container **210** has been removed from initial radix tree **206**, and intermediate radix tree **218** does not include container **210**. In an embodiment, compressor **114** inserts the single element "D" included in container **210** into an auxiliary data structure **233** and stores a reference **240** from the selected container, container **210**, to auxiliary data structure **233**. Auxiliary data structure **233** stores one or more elements included in a container. A container in the radix tree may reference an entry in the auxiliary data structure, which may be any data structure that is capable of storing one or more elements. The auxiliary data structure may be, for example, a table, array, binary tree, or other data structure. In another embodiment, auxiliary data structure **233** is not used and the element included in the immediate child container is discarded when the immediate child container is removed. Regardless of whether auxiliary data structure **233** is used, element "D"'s position in the sequence of elements stored in intermediate radix tree **218** is held by incrementing container **204**'s length, indicating that one element is after the prefix "B".

Removing a given immediate child container from the radix tree may cause the ancestry relationships of the containers in the radix tree to be rearranged. For example, in initial radix tree **206**, a given immediate child container may have a set of one or more immediate child containers. The set of immediate child containers should no longer descend from the given immediate child container because it has been removed from the radix tree and should instead descend from the parent container of the given immediate child container.

In an embodiment, compressor **114** determines whether a given immediate child container (e.g., the immediate child container to be removed) of a parent container is a leaf container. In an example, when the given immediate child container is determined to be a leaf container, compressor **114** may mark the given immediate child container as a leaf container. In another example, when the given immediate child container is determined to be a leaf container, compressor **114** does nothing and traverser **112** continues traversing the remaining containers.

In contrast, when the given immediate child container is determined to not be a leaf container, compressor **114** may identify a set of one or more immediate child containers of the given immediate child container. Compressor **114** may replace the given immediate child container with the parent container as the parent of the set of one or more immediate child containers. In FIG. **2**A, compressor **114** may identify containers **212** and **214** as immediate child containers of container **210**. As illustrated in FIG. **2**B, compressor **114** may replace container **210** with container **204** as the parent of containers **212** and **214**. In such a scenario in which the given immediate child container is determined to not be a leaf container, the set of one or more immediate child containers becomes the immediate child containers of the parent container such that a single edge connects the parent container to each of the containers in the set of one or more immediate child containers. The descendants of the given immediate child container become the descendants of the parent container one level closer to the parent container. Incrementing the parent container's length count and removing the immediate child container in this fashion may provide a faster lookup of keys or key prefixes that are not stored in the radix tree.

3. Continue the Traversal of the Radix Tree

Container **204** has two immediate children, containers **212** and **214**, which are leaf containers. Thus, neither of these containers has a single immediate child container. Traverser **112** may go on to traverse container **208**. In the example illustrated in FIG. **2**B, traverser **112** may traverse container **208**, and identify container **208** as being a parent container that represents a sequence of elements (e.g., sequence of elements "W") and also as having a single immediate child container (e.g., container **215**). Container **208** includes a prefix of the sequence of elements "W" that is represented by container **208**, and container **215** includes a single element "E".

In keeping with the above example, the container threshold is two, and when the length of the sequence of elements that is represented by a parent container is less than the container threshold, the length of the sequence of elements that is represented by the parent container satisfies the container threshold. The length of the sequence of elements that is represented by parent container **208** is one, the value of container **208**'s length field. In such an example, compressor **114** determines whether the length of the sequence of elements that is represented by parent container **208** (e.g., one) is less than two, the container threshold. The length of the sequence of elements that is represented by parent container **208** is less than two. Accordingly, the length of the sequence of elements that is represented by container **208** satisfies the container threshold.

4. The Immediate Child Container is Selected

In an example, compressor **114** selects the immediate child container, which makes the parent container of the immediate child container the non-selected container. In such an example, compressor **114** selects container **215** (the single immediate child container of container **208**) and increments a length of container **215** by the length of the sequence of elements that is represented by the parent container, which is container **208**. Compressor **114** may increment a length of container **215** by incrementing container **215**'s length by one, which is container **208**'s length. Further, when compressor **114** selects container **215**, compressor **114** replaces the prefix of container **215** with the prefix of container **208**. As illustrated in FIG. **2**C, container **215**'s length is incremented by one to incorporate container **208**'s length of one. Accordingly, in FIG. **2**C, the length of the sequence of elements that is represented by immediate child container is two, the value of container **215**'s length field, and the new prefix of container **215** is "W", which is the prefix of container **208**.

Additionally, compressor **114** removes container **208**, the non-selected container, from the radix tree. As illustrated in

FIG. 2C, container **208** has been removed from intermediate radix tree **218**, and intermediate radix tree **242** does not include container **208**. In an embodiment, compressor **114** inserts the single element "E" included in container **215** into auxiliary data structure **233** and stores a reference **244** from the selected container, container **215**, to auxiliary data structure **233**. Regardless of whether auxiliary data structure **233** is used, element "E"'s position in the sequence of elements stored in intermediate radix tree **242** is held by incrementing container **215**'s length, indicating that one element is after the prefix "W".

Removing the immediate child container from the radix tree may cause the ancestry relationships of the containers in the radix tree to be rearranged. For example, in intermediate radix tree **218**, a first parent container (e.g., the parent container to be removed) may be the immediate child of a second parent container. The first parent container may be container **208**, which is an immediate child of container **202** and has container **215** as an immediate child. The immediate child container (e.g., container **215**) should no longer descend from the first parent container (e.g., container **208**) because it has been removed or will be removed from the radix tree. The immediate child container (e.g., container **215**) should instead descend from the second parent container (e.g., container **202**), which is the parent of the first parent container that is to be removed.

In an embodiment, compressor **114** determines whether a first parent container is an immediate child of a second parent container, where the first parent container is the non-selected container and is to be removed from the radix tree. When the first parent container is determined to not be an immediate child of a second parent container, the first parent container may be a root node of the radix tree. In an example, when the first parent container is determined to not be an immediate child of a second parent container, compressor **114** may mark the immediate child of the first parent container as the root node of the radix tree. In another example, when the first parent container is determined to not be an immediate child of a second parent container, compressor **114** may do nothing and traverser **112** may continue traversing the remaining containers.

In contrast, when the first parent container is determined to be an immediate child of the second parent container, compressor **114** may identify a set of one or more immediate child containers of the immediate child container of the first parent container. The set of one or more immediate child containers may be located two depth levels below the first parent container. Compressor **114** may replace the first parent container with the second parent container as the parent of the immediate child container.

In FIG. 2B, compressor **114** may identify container **215** as an immediate child of container **208** and may identify container **208** as an immediate child of container **202**. As illustrated in FIG. 2C, compressor **114** may replace container **208** with container **202** as the parent of container **215**. In such a scenario in which the first parent container is to be removed and is an immediate child of a second parent container, the immediate child container of the first parent container becomes the immediate child of the second parent container such that a single edge connects the second parent container to the immediate child container. The descendants of the immediate child container become the descendants of the second parent container one level closer to the second parent container. Incrementing the immediate child container's length count and removing the first parent container in this fashion may provide a faster lookup of keys or key prefixes that are not stored in the radix tree.

Compressor **114** may make other determinations before removing the non-selected container from initial radix tree **206**. In an example, a container may include a value. Compressor **114** may determine whether the parent container has a value before combining the parent and child containers into a single container. In such an example, when the length of the first set of elements included in the parent container is determined to satisfy the threshold and when the parent container is determined to not have a value, compressor **114** combines the parent and child containers into a single container. Additionally, if the child container (e.g., leaf container) includes a value, compressor **114** may insert the value into the single container. If the child container (e.g., leaf container) includes a reference to the value, compressor **114** may insert the reference into the single container.

5. Continue the Traversal of the Radix Tree

Container **215** is a parent container that has a single immediate child container. Compressor **114** determines whether a length of the sequence of elements that is represented by container **215** satisfies a container threshold. In keeping with the above example, the container threshold is two, and when the length of the sequence of elements that is represented by a parent container is less than the container threshold, the length of the sequence of elements that is represented by the parent container satisfies the container threshold. The length of the sequence of elements that is represented by container **215** is two, the value of container **215**'s length field. In such an example, compressor **114** determines whether the length of the sequence of elements that is represented by container **215** (e.g., two) is less than two, the container threshold. The length of the sequence of elements that is represented by parent container **215** is not less than two. Accordingly, the length of the sequence of elements that is represented by container **215** does not satisfy the container threshold.

Traverser **112** may go on to traverse container **215**'s child, container **216**. Container **216** has a single immediate child container, which is container **217**. Compressor **114** may perform the actions as described in the disclosure to compress intermediate radix tree **242**. For example, compressor **114** increments the length of container **216** by one in order to incorporate container **217**'s length of one and also removes container **217** from the radix tree. As illustrated in FIG. 2D, the length of the sequence of elements that is represented by container **216** is two, container **216**'s length, and container **217** is no longer in the radix tree. Compressor **114** may also inserting the single element "J" included in container **217** into auxiliary data structure **233** and store a reference **248** from container **216** to auxiliary data structure **233**. No more containers are left to traverse in compressed radix tree **280**.

FIG. 2A illustrates an example initial radix tree **206** having nine containers and a depth of four. FIG. 2D illustrates a resulting compressed radix tree after compressor **114** compresses initial radix tree **206** to thereby create compressed radix tree **280**. In FIG. 2D, compressed radix tree **280** stores a subset of the elements that make up the three keys stored in FIG. 2A. In FIG. 2D, compressed radix tree **280** has six containers and a depth of two. In the examples illustrated in FIGS. 2A-2D, compressor **114** reduces initial radix tree **206**'s depth by two (e.g., from a depth of four to two) and the number of containers by three (e.g., from nine to six containers). Thus, compressed radix tree **280** may provide a faster lookup of keys that are not stored in the radix tree as compared to initial radix tree **206**. Additionally, when traverser **112** traverses compressed radix tree **280** to determine whether it stores a particular key or key prefix, compressed radix tree **280** has a shallower depth than initial radix tree **206** and thus

traverser **112** traverses down fewer levels to make this determination as compared to traversing initial radix tree **206** to search for a key or key prefix.

As discussed above and further emphasized here, FIGS. **1** and **2**A-**2**D are merely examples, which should not unduly limit the scope of the claims. For example, it should be understood that one or more modules may be combined with another module. In an example, traverser **112** may be combined with compressor **114**. It should also be understood that a module may be separated into more than one module. In an example, compressor **114** may be separated into a first compressor module and a second compressor module.

Additionally, the prefix threshold may be any number greater than one. For example, the prefix threshold may be three, four, five, or greater. It may be desirable, however, to limit the elements included in a single container such that each container does not consume too much memory. It should also be understood that the prefix threshold may be different for different containers. For example, the prefix threshold of a container may depend on a depth of the container in the radix tree.

Additionally, the container threshold may be any number greater than one. For example, the container threshold may be three, four, five, or greater. It may be desirable, however, to limit the elements included in a single container such that not too many elements of a key are skipped. The smaller the container threshold, the more accurate the search of the radix tree may be. The larger the container threshold, however, the less memory may be consumed by the radix tree and the shallower the depth of the compressed radix tree may be. It should also be understood that the container threshold may be different for different containers. For example, the container threshold of a container may depend on a depth of the container in the radix tree.

Additionally, although the elements have been illustrated in FIGS. **2**A-**2**D as being letters, it should be understood that this is not intended to be limiting. Other embodiments in which an element is different from a letter is within the scope of the disclosure. For example, one or more containers may include bits or other symbols.

III. Example Method

FIG. **3** is a flowchart illustrating a method **300** of compressing a radix tree including a plurality of containers, according to an embodiment. Method **300** is not meant to be limiting and may be used in other applications.

Method **300** includes actions **310**-**360**. In an action **310**, a radix tree including a plurality of containers is traversed. In an example, traverser **112** traverses initial radix tree **206** including containers **202**-**217** in FIG. **2**A. Initial radix tree **206** may store one or more keys or key prefixes. Initial radix tree **206** includes nine containers and has a depth of four. Retriever **104** or radix tree compressor **110** may receive an instruction to compress initial radix tree **206**. Each container in initial radix tree **206** stores a single element that may make up part of a key.

In an action **320**, a parent container that represents a sequence of elements and has a single immediate child container is identifies based on traversal of the radix tree, the parent container including a prefix of the sequence of elements that is represented by the parent container, and the immediate child container including a single element. In the example illustrated in FIG. **2**A, traverser **112** may identify, based on traversing initial radix tree **206**, container **204** as a parent container that represents a sequence of elements (e.g., B) and has a single immediate child container (e.g., container **210**), container **204** including a prefix of the sequence of elements that is represented by container **204**, and container **210** including a single element "D". Container **210** represents one element, "D".

In an action **330**, it is determined whether a length of the sequence of elements that is represented by the parent container satisfies a container threshold. In the example illustrated in FIG. **2**A, compressor **114** may determine whether a length of the sequence of elements that is represented by container **204**, the parent of container **210**, satisfies a container threshold. In an example, the container threshold is two and when the length of the sequence of elements that is represented by container **204** is less than the container threshold, the length of the sequence of elements that is represented by container **204** satisfies the container threshold. In such an example, the length of the sequence of elements that container **204** represents is one, less than the container threshold of two. Thus, compressor **114** determines that the length of the sequence of elements that is represented by container **204** satisfies the container threshold.

When the length is determined to satisfy the container threshold, actions **340**-**360** are performed. In an action **340**, one of the parent container and immediate child container is selected. In an action **350**, a length of the selected container is incremented. In an action **360**, the non-selected container is removed from the radix tree.

In an example, compressor **114** selects container **204**, the parent container. In such an example, container **210**, the immediate child of container **204**, is the non-selected container. Compressor **114** may increment container **204**'s length, which is the length of the sequence of elements that is represented by container **204**, by one. Compressor **114** may also remove container **210** from the radix tree. To adjust the ancestry relationship in the radix tree, compressor **114** may determine whether container **210** is a leaf container. When container **210** is determined to not be a leaf container, compressor **114** may identify a set of one or more immediate child containers of container **210** and replace the container **210** with container **204** as the parent of the set of one or more immediate child containers (see FIG. **2**B).

In another example, compressor **114** selects container **210**, the immediate child container of container **204**. In such an example, container **204**, the parent of container **210**, is the non-selected container. Compressor **114** may increment container **210**'s length, which is the length of the sequence of elements that is represented by container **210**, by the length of the sequence of elements that is represented by container **204**. Compressor **114** may also replace a prefix of container **210** with the prefix of container **204** and remove container **204** from the radix tree. To adjust the ancestry relationship in the radix tree, compressor **114** may determine whether container **204** is an immediate child of a second parent container. In FIG. **2**A, container **204** is an immediate child of container **202**. When container **204** is determined to be an immediate child of the second parent container, compressor **114** replaces the container **204** with the second parent container as the parent of container **210**.

It is also understood that additional processes may be performed before, during, or after actions **310**-**360** discussed above. It is also understood that one or more of the actions of method **300** described herein may be omitted, combined, or performed in a different sequence as desired. In an example, actions **310**-**360** are applied to one or more (or all) containers at each depth level of a radix tree to compress the radix tree.

IV. Example Computing System

FIG. **4** is a block diagram of a computer system **400** suitable for implementing one or more embodiments of the

present disclosure. In various implementations, computing device **102** may include a client or a server computing device that includes one or more processors and may additionally include one or more storage devices each selected from a group including a floppy disk, flexible disk, hard disk, magnetic tape, any other magnetic medium, CD-ROM, any other optical medium, RAM, PROM, EPROM, FLASH-EPROM, any other memory chip or cartridge, and/or any other medium from which a processor or computer is adapted to read. The one or more storage devices may include stored information that may be made available to one or more computing devices and/or computer programs (e.g., clients) coupled to the client or server using a computer network (not shown). The computer network may be any type of network including a LAN, a WAN, an intranet, the Internet, a cloud, and/or any combination of networks thereof that is capable of interconnecting computing devices and/or computer programs in the system.

Computer system **400** includes a bus **402** or other communication mechanism for communicating information data, signals, and information between various components of computer system **400**. Components include an input/output (I/O) component **404** that processes a user action, such as selecting keys from a keypad/keyboard, selecting one or more buttons or links, etc., and sends a corresponding signal to bus **402**. I/O component **404** may also include an output component such as a display **411**, and an input control such as a cursor control **413** (such as a keyboard, keypad, mouse, etc.). An optional audio input/output component **405** may also be included to allow a user to use voice for inputting information by converting audio signals into information signals. Audio I/O component **405** may allow the user to hear audio. A transceiver or network interface **406** transmits and receives signals between computer system **400** and other devices via a communication link **418** to a network. In an embodiment, the transmission is wireless, although other transmission mediums and methods may also be suitable. A processor **412**, which may be a micro-controller, digital signal processor (DSP), or other processing component, processes these various signals, such as for display on computer system **400** or transmission to other devices via communication link **418**. Processor **412** may also control transmission of information, such as cookies or IP addresses, to other devices.

Components of computer system **400** also include a system memory component **414** (e.g., RAM), a static storage component **416** (e.g., ROM), and/or a disk drive **417**. Computer system **400** performs specific operations by processor **412** and other components by executing one or more sequences of instructions contained in system memory component **414**. Logic may be encoded in a computer readable medium, which may refer to any medium that participates in providing instructions to processor **412** for execution. Such a medium may take many forms, including but not limited to, non-volatile media, volatile media, and transmission media. In various implementations, non-volatile media includes optical, or magnetic disks, or solid-state drives, volatile media includes dynamic memory, such as system memory component **414**, and transmission media includes coaxial cables, copper wire, and fiber optics, including wires that include bus **402**. In an embodiment, the logic is encoded in non-transitory computer readable medium. In an example, transmission media may take the form of acoustic or light waves, such as those generated during radio wave, optical, and infrared data communications.

Some common forms of computer readable media include, for example, floppy disk, flexible disk, hard disk, magnetic tape, any other magnetic medium, CD-ROM, any other optical medium, punch cards, paper tape, any other physical medium with patterns of holes, RAM, PROM, EEPROM, FLASH-EEPROM, any other memory chip or cartridge, or any other medium from which a computer is adapted to read.

In various embodiments of the present disclosure, execution of instruction sequences (e.g., method **300**) to practice the present disclosure may be performed by computer system **400**. In various other embodiments of the present disclosure, a plurality of computer systems **400** coupled by communication link **418** to the network (e.g., such as a LAN, WLAN, PTSN, and/or various other wired or wireless networks, including telecommunications, mobile, and cellular phone networks) may perform instruction sequences to practice the present disclosure in coordination with one another.

Where applicable, various embodiments provided by the present disclosure may be implemented using hardware, software, or combinations of hardware and software. Also where applicable, the various hardware components and/or software components set forth herein may be combined into composite components including software, hardware, and/or both without departing from the spirit of the present disclosure. Where applicable, the various hardware components and/or software components set forth herein may be separated into sub-components including software, hardware, or both without departing from the spirit of the present disclosure. In addition, where applicable, it is contemplated that software components may be implemented as hardware components, and vice-versa.

Application software in accordance with the present disclosure may be stored on one or more computer readable mediums. It is also contemplated that the application software identified herein may be implemented using one or more specific purpose computers and/or computer systems, networked and/or otherwise. Where applicable, the ordering of various action described herein may be changed, combined into composite actions, and/or separated into sub-actions to provide features described herein.

The foregoing disclosure is not intended to limit the present disclosure to the precise forms or particular fields of use disclosed. As such, it is contemplated that various alternate embodiments and/or modifications to the present disclosure, whether explicitly described or implied herein, are possible in light of the disclosure. Changes may be made in form and detail without departing from the scope of the present disclosure. Thus, the present disclosure is limited only by the claims.

I claim:

1. A method of compressing a radix tree including a plurality of containers, comprising:

traversing a radix tree including a plurality of containers;

identifying, based on the traversing, a parent container that represents a sequence of elements and has a single immediate child container, the parent container including a prefix of the sequence of elements that is represented by the parent container, and the immediate child container including a single element;

determining whether a length of the sequence of elements that is represented by the parent container satisfies a container threshold; and

when the length is determined to satisfy the container threshold:

selecting one of the parent container and immediate child container;

incrementing a length of the selected container; and

removing the non-selected container from the radix tree.

2. The method of claim **1**, wherein when the length of the sequence of elements that is represented by the parent con-

tainer is less than the container threshold, the length of the sequence of elements satisfies the container threshold.

3. The method of claim **1**, wherein when the length of the sequence of elements that is represented by the parent container does not exceed the container threshold, the length of the sequence of elements satisfies the container threshold.

4. The method of claim **1**, wherein the traversing includes traversing from a root node of the radix tree toward a leaf node of the radix tree.

5. The method of claim **1**, further including:

receiving an instruction to compress the radix tree.

6. The method of claim **1**, further including:

inserting the single element included in the immediate child container into an auxiliary data structure; and

storing a reference from the immediate child container to the auxiliary data structure.

7. The method of claim **1**, wherein when the parent container is selected, the incrementing includes incrementing the length of the sequence of elements that is represented by the parent container by one.

8. The method of claim **7**, further including:

determining whether the immediate child container is a leaf container; and

when the immediate child container is determined to not be a leaf container:

identifying a set of one or more immediate child containers of the immediate child container; and

replacing the immediate child container with the parent container as the parent of the set of one or more immediate child containers.

9. The method of claim **1**, wherein when the immediate child container is selected, the incrementing includes incrementing a length of the immediate child container by the length of the sequence of elements that is represented by the parent container.

10. The method of claim **9**, wherein the immediate child container is selected, the method further including:

replacing a prefix of the immediate child container with the prefix of the parent container.

11. The method of claim **10**, further including:

determining whether the first parent container is an immediate child of a second parent container; and

when the first parent container is determined to be an immediate child of the second parent container, replacing the first parent container with the second parent container as the parent of the immediate child container.

12. A system for compressing a radix tree including a plurality of containers, comprising:

a traverser that traverses a radix tree including a plurality of containers and identifies, based on the traversal of the radix tree, a parent container that represents a sequence of elements and has a single immediate child container, wherein the parent container includes a prefix of the sequence of elements that is represented by the parent container, and the immediate child container includes a single element; and

a compressor that determines whether a length of the sequence of elements that is represented by the parent container satisfies a container threshold, wherein when the length is determined to satisfy the container threshold, the compressor selects one of the parent container and immediate child container, increments a length of the selected container, and removes the non-selected container from the radix tree.

13. The system of claim **12**, wherein when the length of the sequence of elements that is represented by the parent container does not exceed the container threshold, the length of the sequence of elements satisfies the container threshold.

14. The system of claim **12**, wherein the compressor inserts the single element included in the immediate child container into an auxiliary data structure and stores a reference from the immediate child container to the auxiliary data structure.

15. The system of claim **12**, wherein when the compressor selects the parent container, the compressor increments the length of the sequence of elements that is represented by the parent container by one.

16. The system of claim **15**, wherein when the compressor selects the parent container, the compressor determines whether the immediate child container is a leaf container, and wherein when the immediate child container is determined to not be a leaf container, the compressor identifies a set of one or more immediate child containers of the immediate child container and replaces the immediate child container with the parent container as the parent of the set of one or more immediate child containers.

17. The system of claim **12**, wherein when the compressor selects the immediate child container, the compressor increments a length of the immediate child container by the length of the sequence of elements that is represented by the parent container.

18. The system of claim **17**, wherein when the compressor selects the immediate child container, the compressor replaces a prefix of the immediate child container with the prefix of the parent container.

19. The system of claim **18**, wherein when the compressor selects the immediate child container, the compressor determines whether the first parent container is an immediate child of a second parent container, and wherein when the first parent container is determined to be an immediate child of the second parent container, the compressor replaces the first parent container with the second parent container as the parent of the immediate child container.

20. A machine-readable medium comprising a plurality of machine-readable instructions that when executed by one or more processors is adapted to cause the one or more processors to perform a method comprising:

traversing a radix tree including a plurality of containers;

identifying, based on the traversing, a parent container that represents a sequence of elements and has a single immediate child container, the parent container including a prefix of the sequence of elements that is represented by the parent container, and the immediate child container including a single element;

determining whether a length of the sequence of elements that is represented by the parent container satisfies a container threshold; and

when the length is determined to satisfy the container threshold:

selecting one of the parent container and immediate child container;

incrementing a length of the selected container; and

removing the non-selected container from the radix tree.

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